IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 04, 2016 | ISSN (online): 2321-0613

Effect of Variation in Inlet Air Temperature on Emission Gas and Fuel Economy for Single Cylinder 4 – Stroke Spark Ignition Engine

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Abstract— Exhaust gas contains many harmful and toxic gases like CO, HC, NOX etc. which has a harmful effect on human being like as cancer, asthma, skin disease etc. and also causes global warming [1]. In the present research work, authors have studied the effect on pollutant of exhaust gas by varying the inlet air temperature for the single cylinder 4-stroke petrol engine and effect on fuel economy. The variation in inlet air temperature has been carried out by using the exhaust gas heat which is escape in atmosphere as a waste heat. For the variation in the inlet air temperature with the help of exhaust gases, double pipe heat exchanger is designed for the experimental work. Authors have recorded different observations for exhaust gas composition for the various inlet air temperatures with the help of exhaust gas analyzer. From the experimentation, it has been observed that exhaust gas composition improves and content of HC and CO reduces when inlet air is supplied at higher temperature than atmosphere. It has also found that the fuel economy improves with when inlet air is supplied at higher temperature than atmosphere because of perfect combustion of fuel[1]

Key words: Air Temperature, 4 – Stroke Spark Ignition Engine

I. INTRODUCTION

In today's world, there are so many problems related to energy, environment, pollution etc. among them global warming and the pollution are directly affecting problems to the human beings. The pollution done by the automobile increases day by day as the number of automobile usage is increasing. The exhaust gas emitted from the automobile consists of some harmful gases like CO, HC and NOx[1]. These gases dissolve into the atmosphere, may cause very much damage to the environment in many means, like it can cause acid rain, global warming, glacier melting etc. The automobile using any fuel cannot convert the whole energy that is generated by the fuel combustion into the useful work. Most of the heat generated due to combustion will get wasted in the form of exhaust gas heat [1]. Many researchers have proposed the methods for reducing the amount of harmful gases in the exhaust gas and also to recover the heat that is being wasted by the exhaust gas [2]. For the purpose of better utilization of fuel and to reduce the harmful gases in emission, need to make the combustion process efficient in the engine [3]. In the present work, authors have attempted to solve the problem of emissions of harmful gases and recover the heat energy that is being wasted into the atmosphere.

The main objective of this paper is to study the effect of variation in inlet air temperature on emission of exhaust gases and fuel economy of single cylinder 4-stroke spark ignition engine. For the variation in inlet air temperature, waste heat of exhaust gas is utilized. For heat transfer, authors have designed the double pipe heat exchanger based on exhaust gas temperature and experimentation has been carried out. In double pipe heat exchanger, inlet air passes through internal pipe and exhaust gas passes through outer pipe. Due to temperature difference between both fluids, the heat transfer occurs from hot fluid to cold fluid [5]. For the measurement of fuel consumption in the engine, time is measured for burning the same quantity of fuel with and without air preheating concept.

II. DESIGN OF HEAT EXCHANGER

For the purpose of heat exchange between the inlet air and the exhaust gases, authors have designed counter flow arrangement - double pipe type heat exchanger [6] based on exhaust gas temperature. In order to obtain the different temperature of inlet air, heat exchanger is designed for the maximum temperature of exhaust gas. The inlet air passes through inner tube of heat exchanger and exhaust gas passes through outer pipe. For designing of heat exchanger, standard procedure has been followed [7]. For the inner tube, copper material is selected as it has maximum thermal conductivity so that the maximum heat transfer occurs from exhaust gas. Following the standard design procedure, the dimensions of heat exchanger obtained are: length of heat exchanger 600 mm, inner diameter of inner pipe 38 mm, outer diameter of inner pipe 42 mm, inner diameter of outer pipe 65 mm and outer diameter of outer pipe 75 mm. Annulus is made of mild steel to minimize heat lost in atmosphere. Small holes are provided for thermocouples to measure inlet air temperature. These holes are also helpful for easy removal of thermocouples for the cleaning of the thermocouples.

The nomenclatures for the design of the heat exchanger are shown here. Also the data taken for the designing of the heat exchanger is provided below the nomenclatures.

Symbol	Description
A	Cross-sectional area
C_p	Specific Heat at constant pressure
D	Tube diameter
D_b	Bubble diameter
D_s	Shell diameter
D_e	Equivalent diameter
F_l	Fouling Factor
f	Tube Size mass Velocity
h_o	External Fouling Factor
h_i	Internal Fouling Factor
K_w	Thermal Conductivity
m_c	Cold Mass Flow Rate
m_h	Hot Mass Flow Rate
$LMTD$	Logarithmic Mean Temperature Difference
P_r	Prandtl Number
δP	Pressure Drop

R	Reynold Number
T_{hi}	Hot Fluid Inlet Temperature
T_{ho}	Hot Fluid Outlet Temperature
T_{ci}	Cold Fluid Inlet Temperature
T_{co}	Cold Fluid Outlet Temperature
Θ	Crank Angle
δT_m	Mean Temperature
U	Heat Transfer Coefficient
V	Tube Velocity
V_m	Tube Size mass Velocity

Table 1: Data of Properties of Hot Air

Temperature of cold air in K	303
Temperature of cold air out in K	343
Specific heat of cold air in KJ/Kg-K	1.005
Velocity after air filter in m/s	0.4
Area of air filter outlet in m³	0.00303
Density of cold air in Kg/m³	1.165
Dynamic viscosity of cold air in Kg/m-s	0.0000197
Thermal conductivity of cold air in W/m-K	0.0282
Internal diameter of annulus in m	0.065
Outer diameter of annulus in m	0.075
hydraulic diameter of cold air in m	0.023

Table 2: Data of Properties of Cold Air

Using standard double pipe heat exchanger design procedure [7], authors have designed the heat exchanger as follows,

$m_c = \rho_c A_c V_c$ $\quad$ $m_h = \rho_h A_h V_h$

=1.265*0.00303*0.4 $\quad$ = 1.1225*0.00019*7.8

= 0.0014 kg/s $\quad$ = 0.00166354 kg/s

$$Q = m_c cp_c (Tco - Tci)$$
= 0.0014*1.005(343-303)
= 0.05676 kJ

$$Q = m_h cp_h (Tho - Thi)$$
:.0.05676 = 0.0016635*1.151(673- Thi)

:. Thi =643.3554 K

$$LMTD = \frac{(Thi - Tco) - (Tho - Tci)}{ln\frac{(Thi-Tco)}{(Tho-Tci)}}$$
$$= \frac{(673-343)-(643.35-303)}{ln\frac{(673-343)}{(643.35-303)}}$$
= 335.15 K

For the design of heat exchanger, initially value of U is assumed to be 10 W/m² °C and various iterations has been carried out. But final iteration is presented in this paper.

$$A = \frac{Q}{U.\Delta T_m}$$
$$= \frac{0.05676}{10 \times 335.15}$$
=0.04838 m²

A=π×D×L

:. 0.04838=π×0.038×L

:.L=40.533 cm

$G_{mh} = \frac{m_h}{\frac{\pi d_i^2}{4}} = \frac{0.00166}{\frac{\pi\times(0.038)^2}{4}}$ =1.4668

$v = \frac{G_{mh}}{\rho_h} = \frac{1.4668}{0.525}$ =2.7939 m/s

$Pr_h = \frac{\mu_{ph} C_{ph}}{k_h} = \frac{0.0000317\times1.151}{0.0466}$ = 0.7829

$Re_h = \frac{4\times m_h}{\pi d_i \mu_h} = \frac{4\times0.0016635}{\pi\times0.038\times0.0000317}$ = 1758.33

$$h_i = 1.86\frac{k_{fh}}{d_i}(Re_h.\mathrm{Pr_h})^{0.33}(\frac{d_i}{L})^{0.33}$$
= 11.25 W/m² –K

$G_{mc} = \frac{m_c}{\frac{\pi(d_s^2-d_0^2)}{4}} = \frac{0.0014}{\frac{\pi(0.065^2-0.042^2)}{4}}$ =0.73kg/s-m²

$v = \frac{G_{mc}}{\rho_c} = \frac{0.73}{1.165}$ =0.6270 m/s

P_r = 0.698

Re = $\frac{\rho_c V_c (d_s - d_o)}{\mu_c} = \frac{1.165\times0.627\times(0.065-0.042)}{0.0000197}$ = 948.90

$$h_o = 1.86\frac{k_{fc}}{d_o}(Re_c.\mathrm{Pr_c})^{0.33}(\frac{d_o}{L})^{0.33}$$
= 5.823 W/m² –K

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{1}{h_{di}} + \frac{d_i \ln(^{d_o}/_{d_i})}{2k_w} + \frac{d_i}{d_o h_{do}} + \frac{d_i}{d_o h_o}}$$
= 4.0777 W/m²-k

$$U_o = \frac{1}{\frac{1}{h_o} + \frac{1}{h_{do}} + \frac{d_o \ln(^{d_o}/_{d_i})}{2k_w} + \frac{d_o}{d_i h_o} + \frac{d_o}{d_i h_{di}}}$$
= 3.69 W/m²-k

The value of Ui and Uo is nearer to assumed value of U. Thus, the length of heat exchanger is obtained in final iteration is 40 cm but due to variation in speed of engine and variation required in inlet air temperature; heat exchanger has been fabricated of 60 cm length to accommodate all the variants.

III. LAYOUT OF EXPERIMENTAL SETUP

In experimental set up, an arrangement has been made to obtain the different inlet air temperature at same exhaust temperature. To obtain the different inlet air temperatures, the flow of hot exhaust gas through heat exchanger is maintained as per the requirement and excess exhaust gas is bypassed from the system without contributing the heat transfer by providing two valve, one at bypass and other at heat exchanger inlet. By operating two valves, flow can be adjusted to obtain different inlet air temperature.

The layout of experimental setup is shown below.

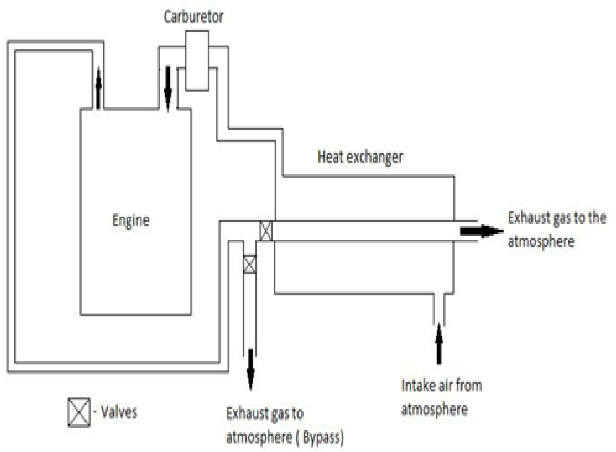

Fig. 1: Layout of experimental setup

As shown in fig-1, the exhaust gas is directed from the engine outlet to the heat exchanger. The T- joint is provided for directing exhaust gas in two directions, one at bypass and other at inlet of heat exchanger. In order to reduce the heat lost in atmosphere, between the engine outlet and inlet of heat exchanger, glass wool insulation in provided on pipe. The exhaust gas can be directed to atmosphere or to the heat exchanger as per the requirement of inlet air temperature.

Also partial flow in both directions can be attained using proper valve opening. Figure -2 and 3shows the setup for the experimentation. The experiment is conducted on the 4 stroke 100 cc petrol engine of bajaj Kawasaki bike.

IV. PROCEDURE FOR EXPERIMENTATION

Initially, the speed of engine is set at 1900-2100 RPM for 10 minutes. During this period of time, the exhaust gases pass through bypass valve to atmosphere so observations at the atmospheric temperature can be recorded. Then bypass valve is closed and the valve in path of heat exchanger is opened, so exhaust gases pass through the heat exchanger. In heat exchanger, inlet air temperature is increased by the exhaust gases, and desire temperatures can be obtained. After attaining the desire temperature, observations of exhaust gas composition using exhaust gas analyzer are recorded. The observations for exhaust gas composition are recorded for the different inlet air temperatures 27 ^{0}C, 37 ^{0}C, 43 ^{0}C, 49 ^{0}C, 58 ^{0}C, 63 ^{0}C and 66 ^{0}C.

Fig. 2: Experimental setup

Fig. 3: Top view of experimental setup

With the variation in speed of engine, the temperature and composition of exhaust gases also varies. So the experiment is conducted at both the conditions, low speed and high speed [8].

Following same procedure, observations are taken at speed range of 2800-3000 RPM at different temperatures 27 0C, 43 0C, 47 0C, 53 0C¸ 63 0C¸ 70 0C and 80 0C.

For the measurement of consumption of fuel, the fuel inlet valve of bike is shut off after the ideal run of 10 minute and then time is measured till the bike is shut off. Then same procedure is followed when inlet air temperature is reached at around 55-600C using the attachments.

V. OBSERVATION

The readings of exhaust gas emissions are as per table which is shown below.

Temperature ^{o}C	HC in ppm	CO %	CO_2 %
27	4776	4.8	1.95
37	5345	6.9	2.97
43	5190	4.22	1.68
49	2720	7.29	3.67
58	3667	6.72	2.99
63	2358	5.82	2.79
66	2609	9.69	4.45

Table 3: Exhaust gas composition at different temperature at 1900-2100 RPM range

Temperature ^{o}C	HC in ppm	CO %	CO_2 %
27	2047	9.41	4.17
43	2245	8.28	3.54
47	1503	7.33	3.14
53	1919	9.28	3.86
63	2197	9.31	3.99
70	2549	6.79	3.01
80	3102	8.92	3.96

Table 4: Exhaust gas composition at different temperature at 2800-3000 RPM range

VI. RESULTS

Chart-1 and chart -2 shows the variation in HC (in ppm) in exhaust gas with inlet air temperature for 1900-2100 rpm range and 2800-3000 rpm range respectively.

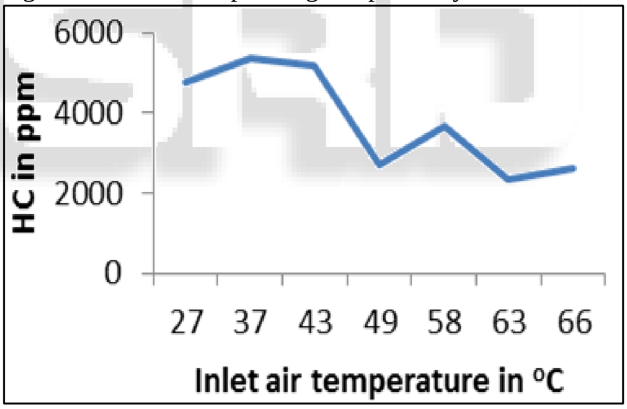

Fig. 4: Chart 1: HC vs inlet air temperature at 1900-2100 rpm range

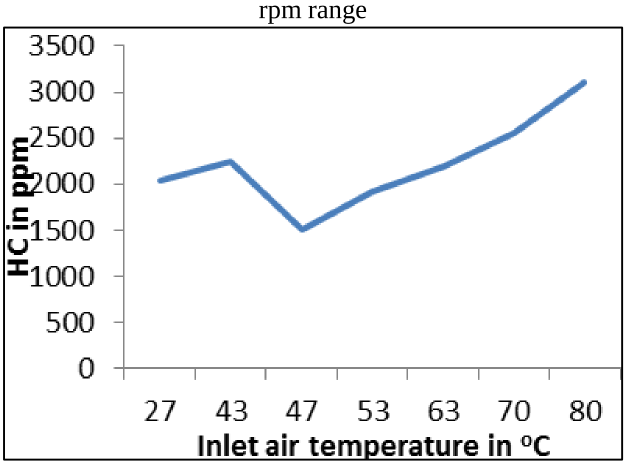

Fig. 5: Chart 2: HC vs inlet air temperature at 2800-3000 rpm range

Chart-3 and chart -4 shows the variation in % CO2 in exhaust gas with inlet air temperature for 1900-2100 rpm range and 2800-3000 rpm range respectively.

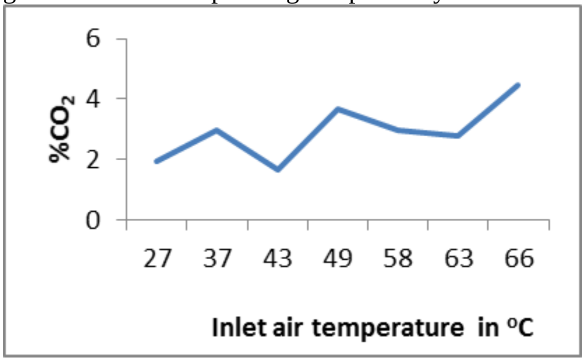

Fig. 6: Chart 3: %CO2 vs inlet air temperature at 1900-2100 rpm range

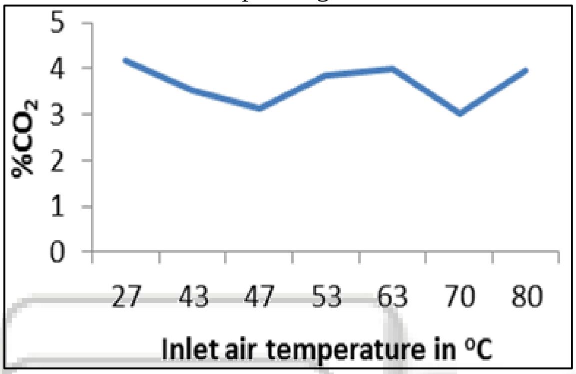

Fig. 7: Chart 4: %CO2 vs inlet air temperature at 2800-3000 rpm range

Chart-5 and chart - 6 shows the variation in % CO in exhaust gas with inlet air temperature for 1900-2100 rpm range and 2800-3000 rpm range respectively

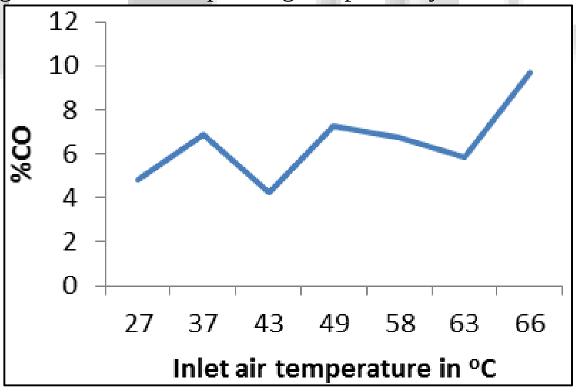

Fig. 8: Chart 5: %CO vs inlet air temperature at 1900-2100 rpm range

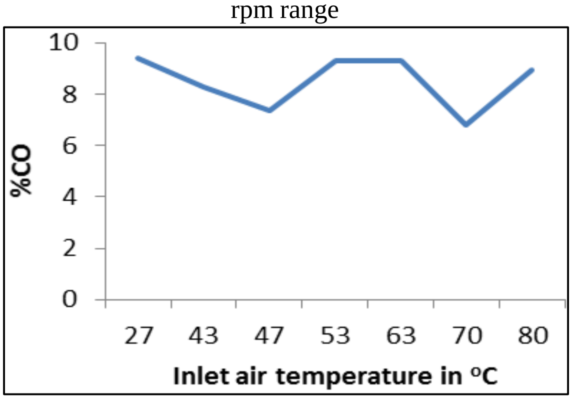

Fig. 9: Chart 6: %CO vs inlet air temperature at 2800-3000 rpm range

Also, the time taken for the engine to shut off without the experimental attachment as per the procedure stated above, is 3 minutes and 4 seconds while using the setup and entering air at around 55-60oC, the shutting off time is noted 3 minute and 48 seconds.

VII. CONCLUSION

From the observations, it has been found that the HC and CO in exhaust gas reduces when inlet air is supplied at temperature (up to the certain limit) higher than the atmospheric temperature. From the study of the observations and the working condition, optimum temperature range, at which inlet air is supplied, can be found at which HC and CO reduces as the complete combustion of fuel occurs in engine.

From the measurement of fuel consumption, it has been found that fuel economy increases when inlet air is supplied at temperature higher than the atmospheric temperature. It has also been observed during experimentation, smooth operation of engine is occurred when inlet air is supplied at temperature higher than the atmospheric temperature.

VIII. ACKNOWLEDGEMENT

Authors would like to thank Prof. K.D. Tandel for the guidance in fabrication of the attachment. Authors are also thankful to Mr. Sanjay Modh for support of electrical equipment used in the experiment. The guidance of Mr. Piyush Desai for the insulation related problem is appreciated.

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